Coupling High-Resolution Earth System Models Using Advanced Computational Technologies

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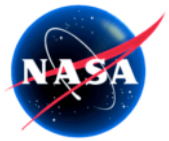


Outline

- Background
- Earth System Models
- Coupling Design
- Computational Aspects
- Science Aspects
- Highlights
- Future Directions

Background: Objectives

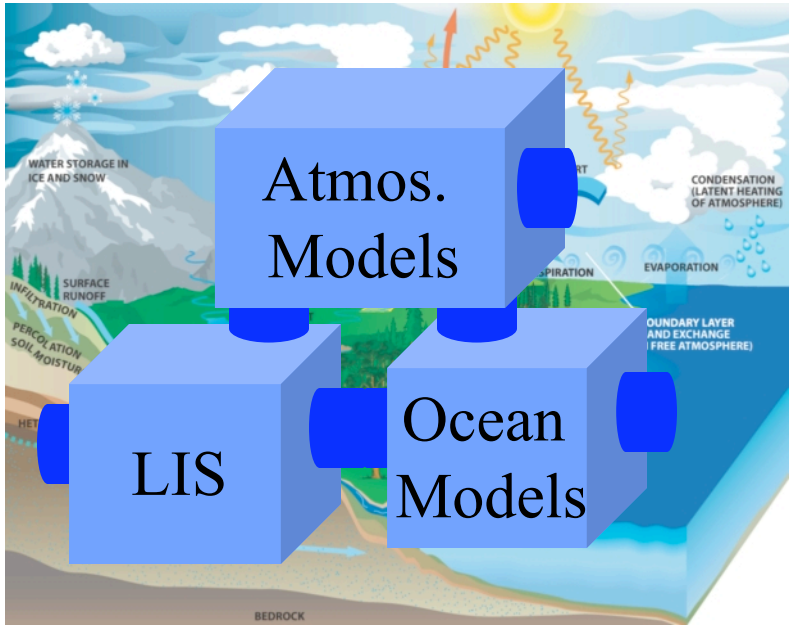
- Apply advanced computational technologies to the problem of coupling high-resolution Earth system models

- Combine the emerging technologies of the
  - Earth System Modeling Framework (ESMF),
  - the Land Information System (LIS); and
  - the Grid Analysis and Display System (GrADS)/ Distributed Oceanographic Data System (DODS)

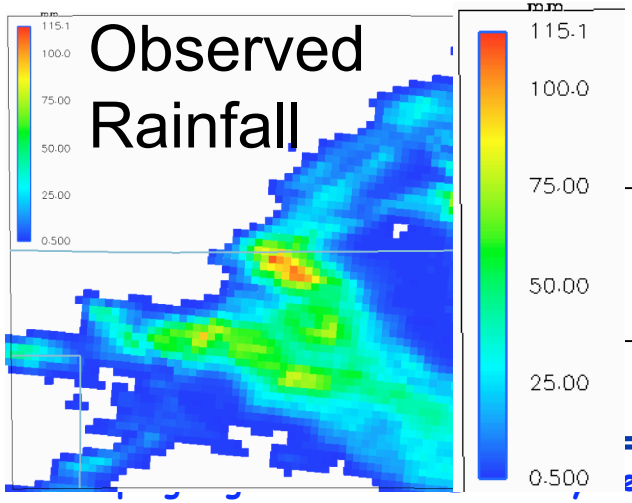
- Couple LIS to the
  - The Weather Research and Forecasting (WRF) model and
  - the Goddard Cumulus Ensemble (GCE) model

Background: Why Couple?

To improve water and energy cycle prediction

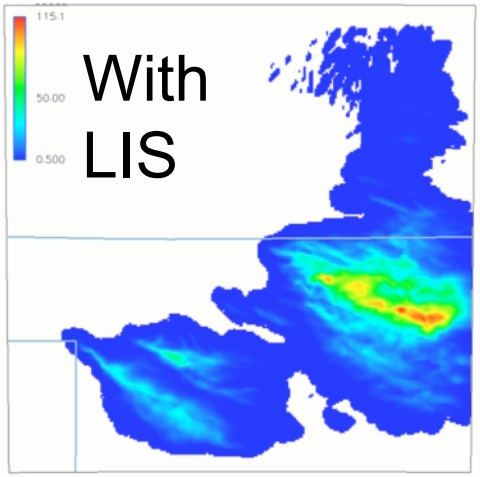


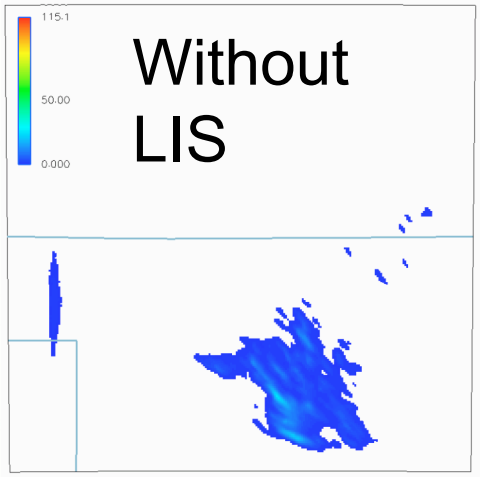
LIS Impact Preview: Coupling to a Weather Model



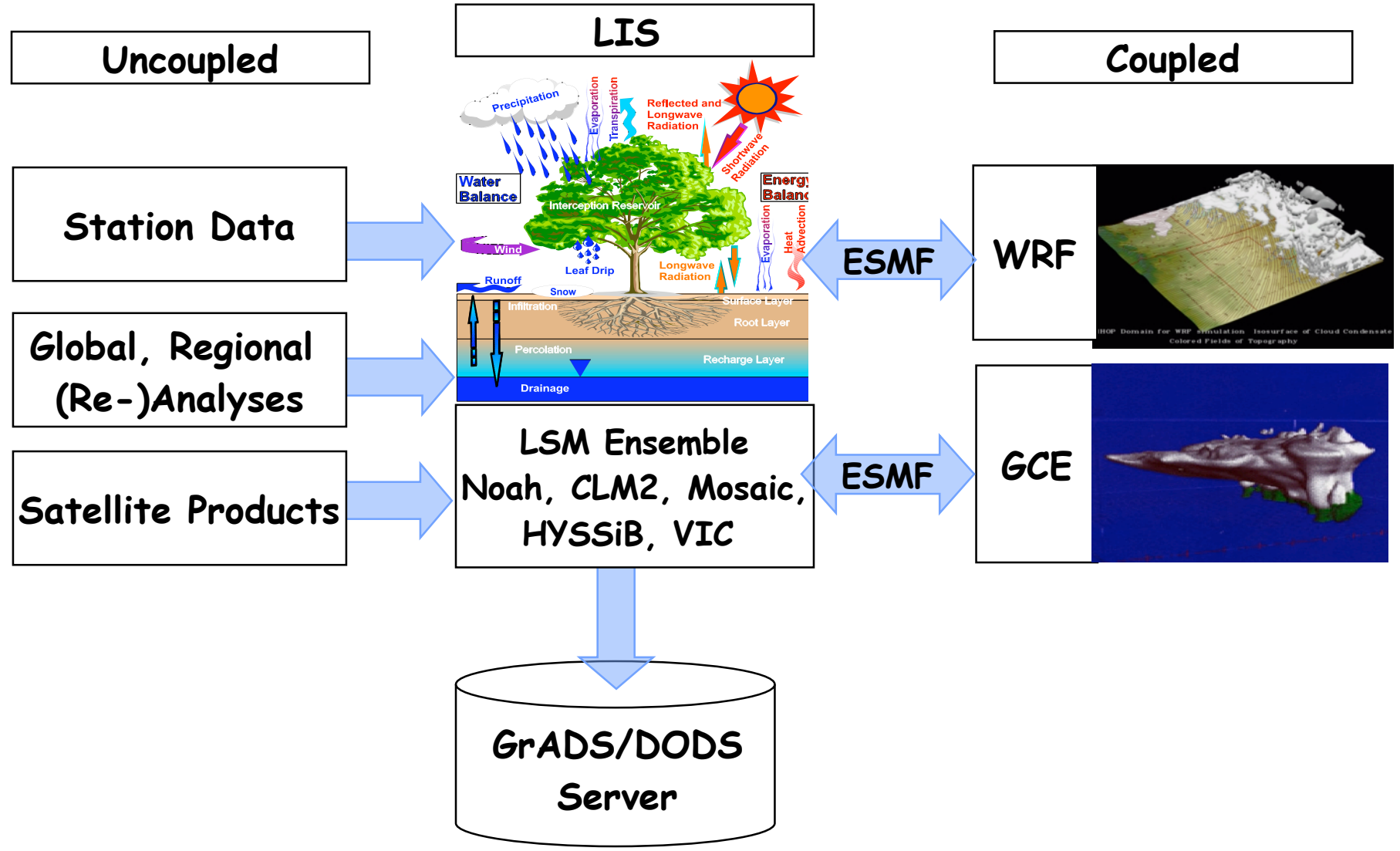
12-Hours Ahead Atmospheric Model Forecasts

em Models Using Adv





Background: LIS Execution Modes



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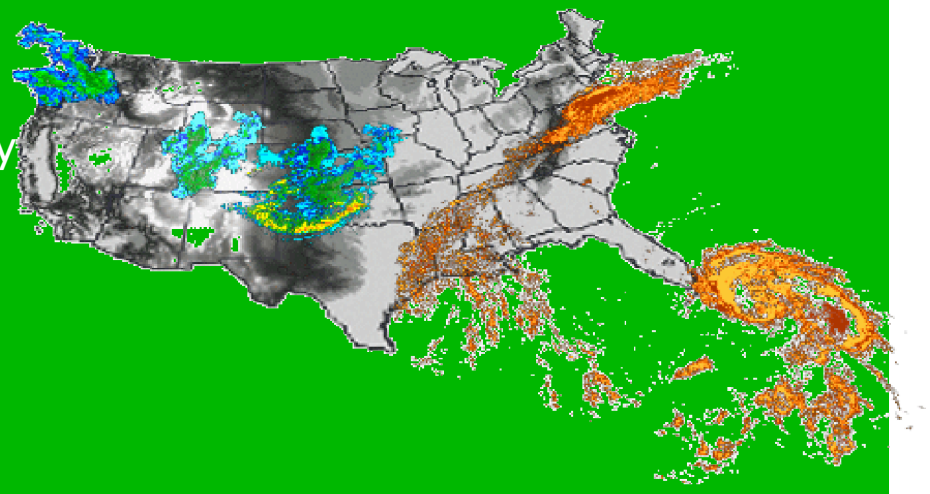
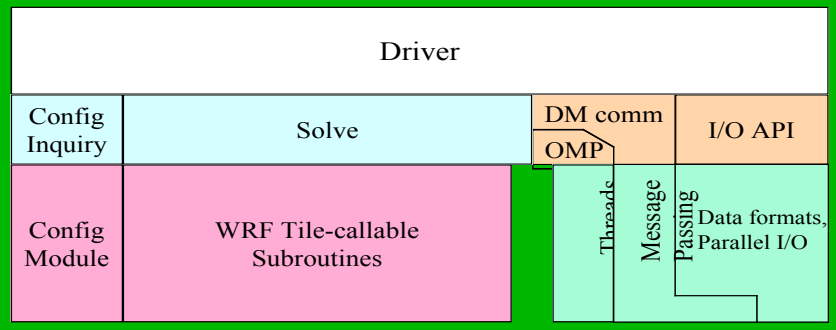
Weather Research and Forecasting (WRF) Model

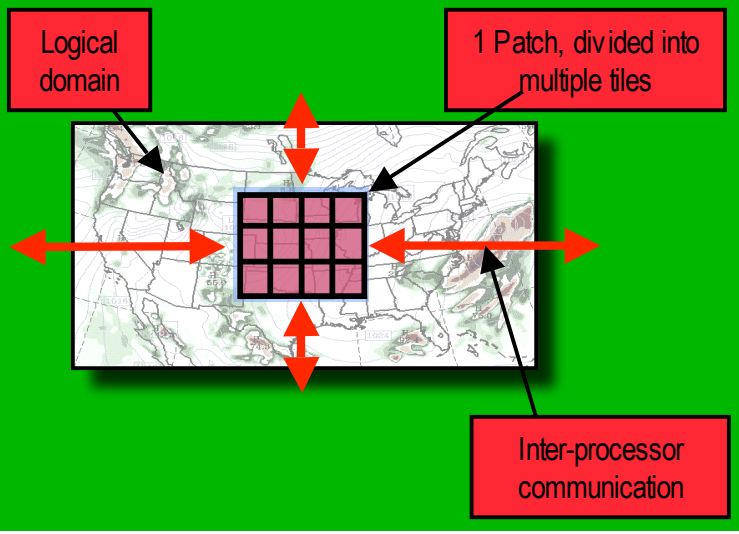
http://www.wrf-model.org

Aspects of Design

- Single-source code
- Fortran90 modules, dynamic memory structures, recursion
- Hierarchical design
  - Driver layer
  - Model layer
  - Mediation layer
- Multi-level parallelism







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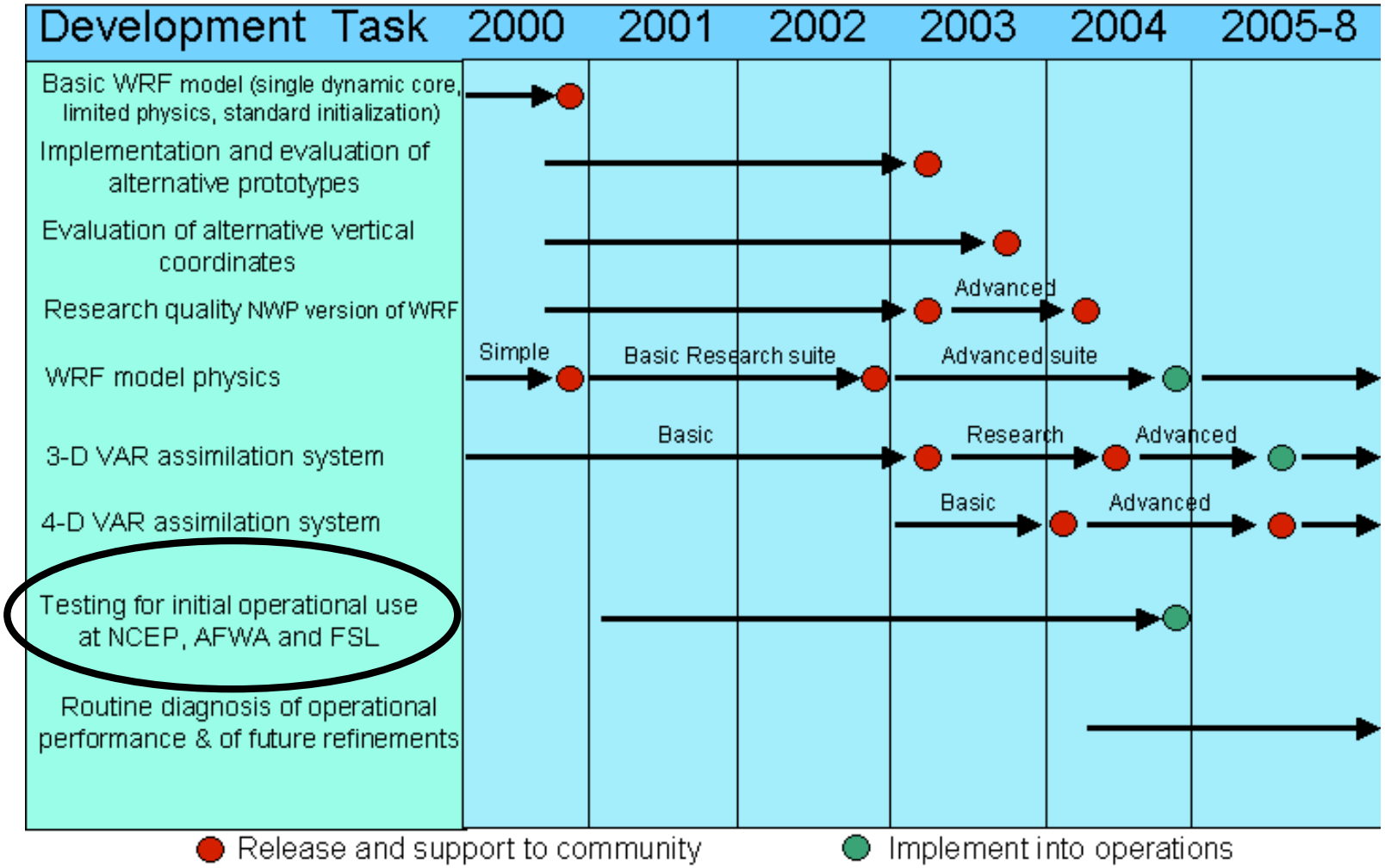
Weather Research and Forecasting Model

http://www.wrf-model.org



NWP=Numerical Weather Prediction; VAR=variational; NCEP=National Centers for Environmental Prediction; AFWA=Air Force Weather Agency; FSL=Forecast Systems Laboratory

WRF Status

WRF V2.0 Release (May 18, 2004; V2.0.2 October, 2004, V2.0.3.1 December 2004)

http://www.wrf-model.org

- **What is in WRF V2.0?**
- Advanced Research WRF (ARW) dynamical core:
  - Eulerian mass coordinate
- One-way and two-way nesting
- New physics options, including :
  - Noah Land Surface Model (LSM),
  - Rapid Update Cycle (RUC) LSM,
  - Ysu Planetary Boundary Layer (PBL), and
  - Grell-Devenyi ensemble cumulus scheme
- ESMF time manager
- Enhanced I/O options
- Enhanced Runtime System Library (RSL)
- New Standard Initialization (SI) V2.0
- WRF 3-Dimensional Variational Assimilation (3DVAR) V2.0

Key project requirement

Not actually ESMF, but a recoded F90 version of ESMF!!

Built on Message Passing Interface

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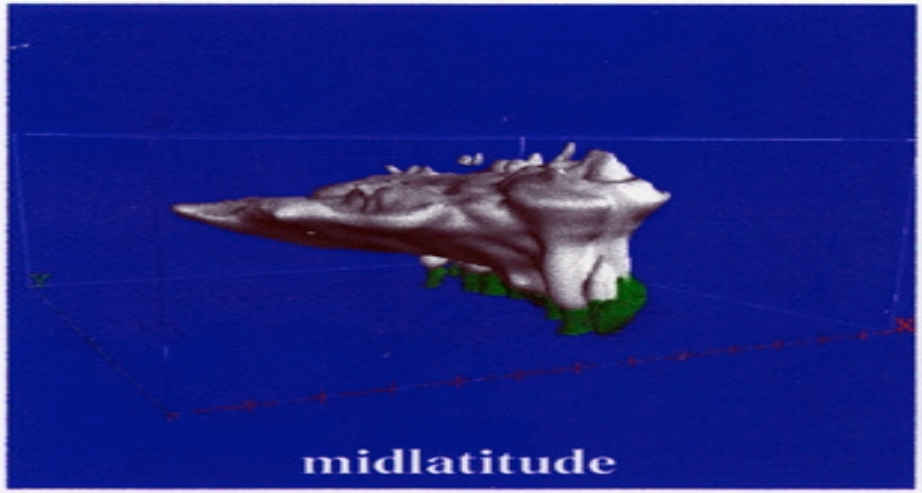
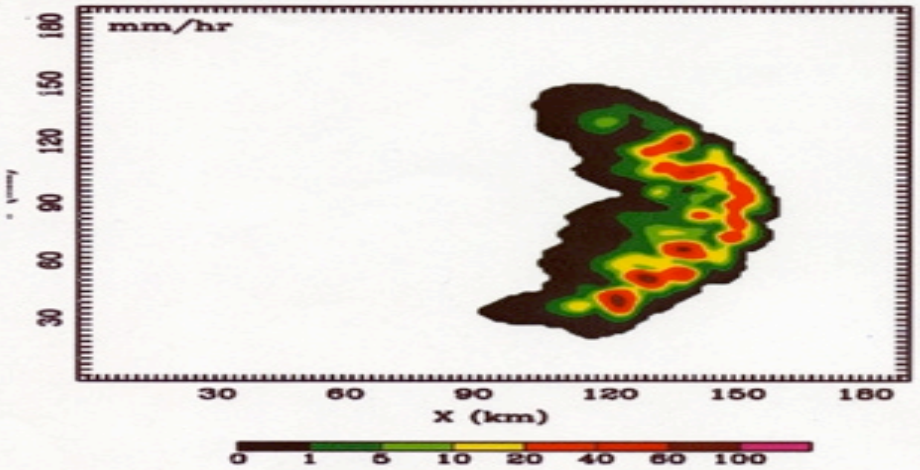
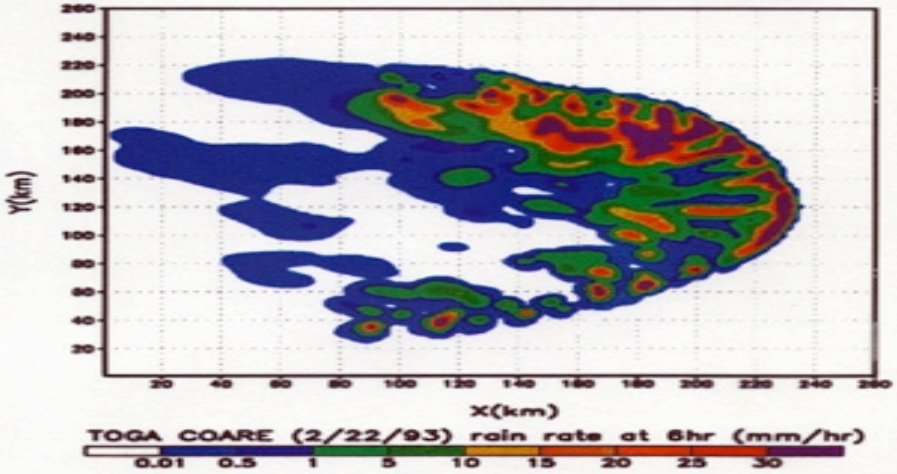
Goddard Cumulus Ensemble (GCE) Model

Parameters/Processes	GCE Model
Dynamics	Anelastic or Compressible 2D (Slab- and Axis-symmetric) and 3D
Vertical Coordinate	Z (p, terrain)
Microphysics	2-Class Water & 3-Class Ice 2-Class Water & 2-Moment 4-Class Ice Spectral-Bin Microphysics
Numerical Methods	Positive Definite Advection for Scalar Variables; 4th-Order for Dynamic Variables
Initialization	Initial Conditions with Forcing from Observations/Large-Scale Models
FDDA	Nudging
Radiation	k-Distribution and Four-Stream Discrete-Ordinate Scattering (8 bands) Explicit Cloud-Radiation Interaction
Sub-Grid Diffusion	TKE (1.5 order)
Surface Processes	Ocean Mixed Layer 7-Layer Soil Model (PLACE) CLM - LIS TOGA COARE Flux Module
Parallelization	OPEN-MP and MPI

Goddard Cumulus Ensemble Model Simulations







* both squall–line systems contain heavy precipitation along the leading edge with an area of trailing stratiform rain. heavy rainfall along the leading edge originates from warm rain processes in the tropical system and from the melting of large ice in the midlatitude system
* the midlatitude system produces stronger updrafts and more ice aloft as a result of greater instability, while the tropical system has a much larger stratiform region as result of a moister environment.
* both simulations agree well with observations and yield cloud data sets that are used to develop rainfall and heating algorithms.

W.–K. Tao (Code 912, NASA GSFC), S. Lang (Code 912,SSAI), Y. Wang (Code 912, JCET)

The Goddard Cumulus Ensemble Model

http://rsd.gsfc.nasa.gov/912/code912/model.html

GCE V1.0 Release (June, 2004)

What is in GCE V1.0?

Place Land Surface Model (LSM)

Message Passing Interface (MPI) parallelization

Cyclic lateral boundary conditions

Project advancement

GCE V2.0 Release (Expected July, 2005)

What will be in GCE V2.0?

Place and all LIS LSMs

ESMF Virtual Machine [illegible] MPI parallelism

Cyclic and open bound[illegible]

2D vs. 3D

Project advancements

Key project requirement

The Earth System Modeling Framework (ESMF)

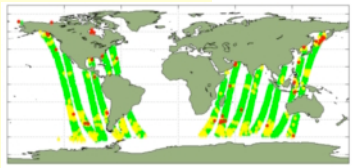
http://www.esmf.ucar.edu

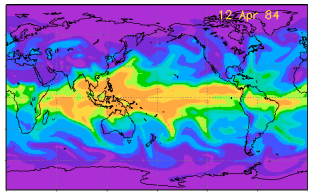
Climate

Weather

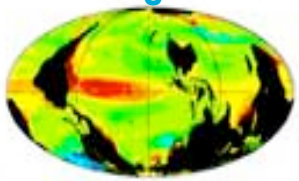
Data Assimilation

NASA GSFC PSAS



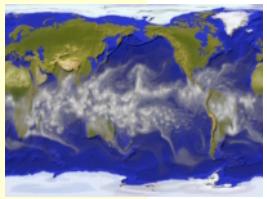


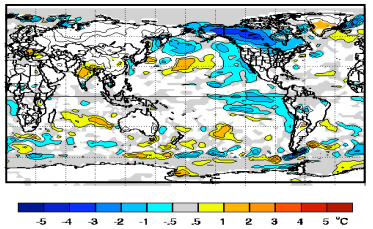
MITgcm



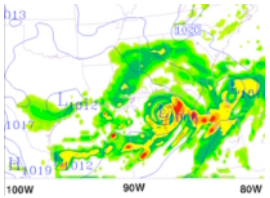
GFDL FMS Suite

NCAR/LANL CCSM





NCEP Forecast



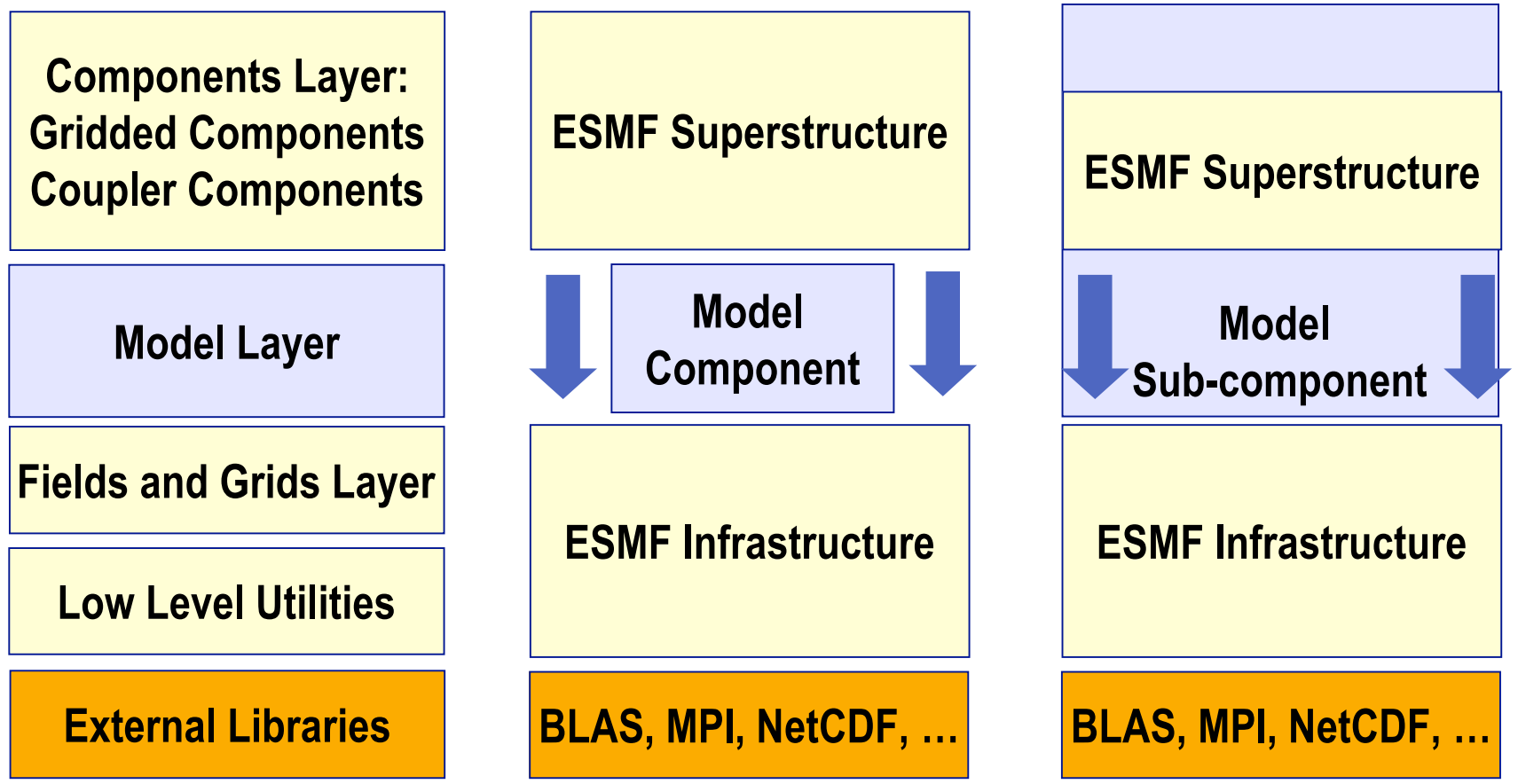
NSIPP Seasonal Forecast

C. DeLuca/NCAR, J. Anderson/NCAR, V. Balaji/GFDL, B. Boville/NCAR, N. Collins/NCAR, T. Craig/NCAR, C. Cruz/GSFC, A. da Silva/GSFC, R. Hallberg/GFDL, C. Hill/MIT, M. Iredell/NCEP, R. Jacob/ANL, P. Jones/LANL, B. Kauffman/NCAR, J. Larson/ANL, J. Michalakes/NCAR, E. Schwab/NCAR, S. Smithline/GFDL, Q. Stout/U Mich, M. Suarez/GSFC, A. Trayanov/GSFC, S. Vasquez/NCAR, J. Wolfe/NCAR, W. Yang/NCEP, M. Young/NCEP and L. Zaslavsky/GSFC

ESMF Status
http://www.esmf.ucar.edu

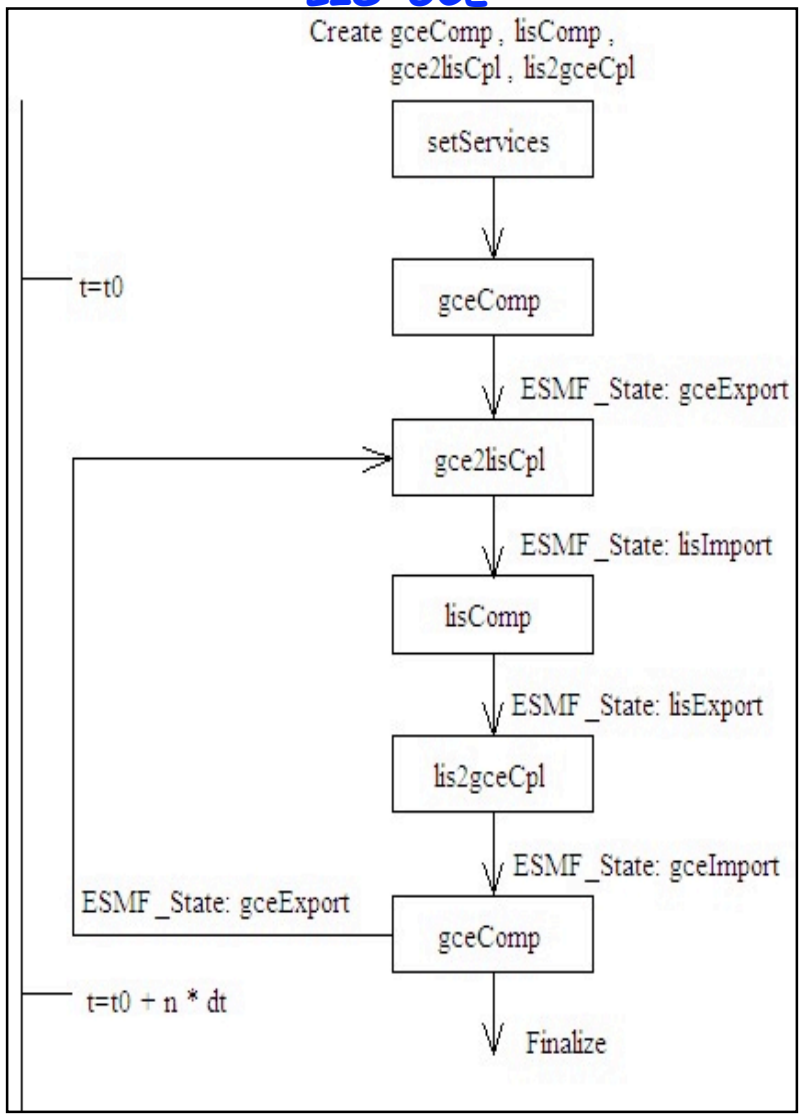
Planned (Actual)	Milestone
May 2002	Draft Developer's Guide and Requirements Document completed 1st Community Requirements Meeting and review held in D.C.
July 2002	ESMF VAlidation (EVA) suite assembled
August 2002	Architecture Document: major classes and their relationships Implementation Report: language strategy and programming model Software Build and Test Plan: sequencing and validation
May 2003	ESMF Version 1.0 release, 2nd Community Meeting at GFDL
November 2003	First 3 interoperability experiments completed
April 2004 (July 2004)	Second API and Version 2.0 software release, 3rd Community Meeting (Version 2.0.2 released in October 2004; and Version 2.1.0rp2 released in March 11, 2005)
November 2004 (Expected Nov 2005)	All interoperability experiments complete; all testbed applications compliant
January 2005 (Expected Jan 2006)	Final delivery of source code and documentation

ESMF coupling schematic

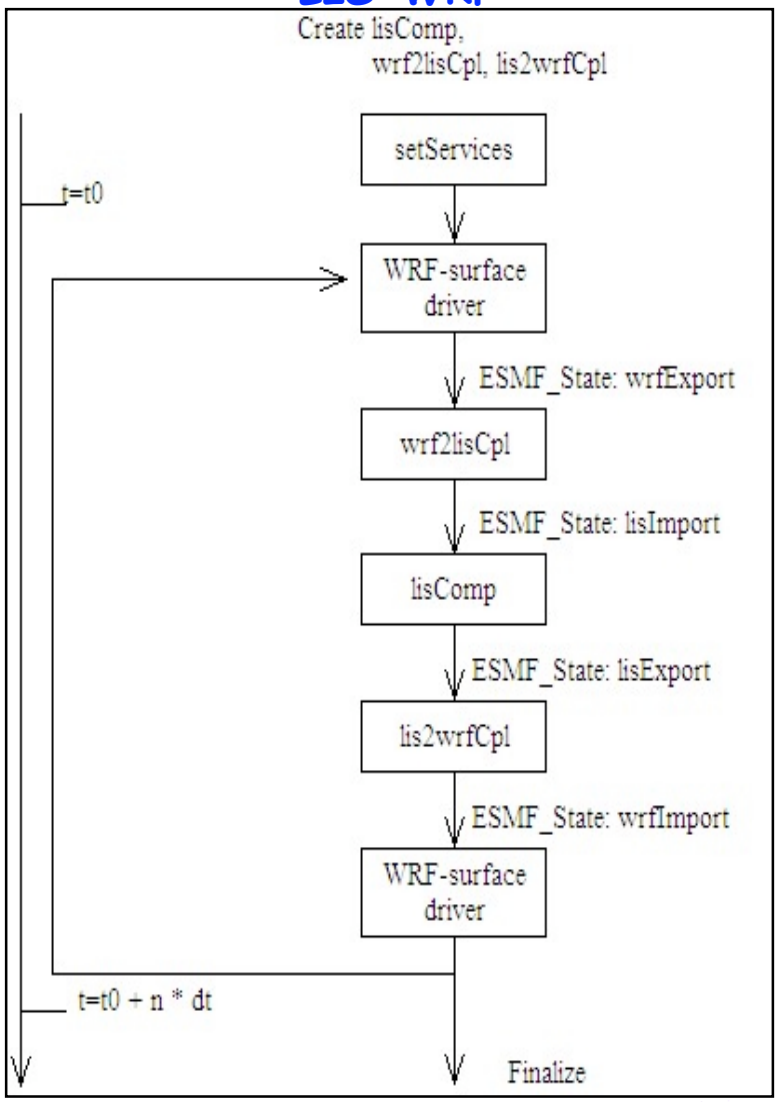


LIS-GCE and LIS-WRF coupling

LIS-GCE

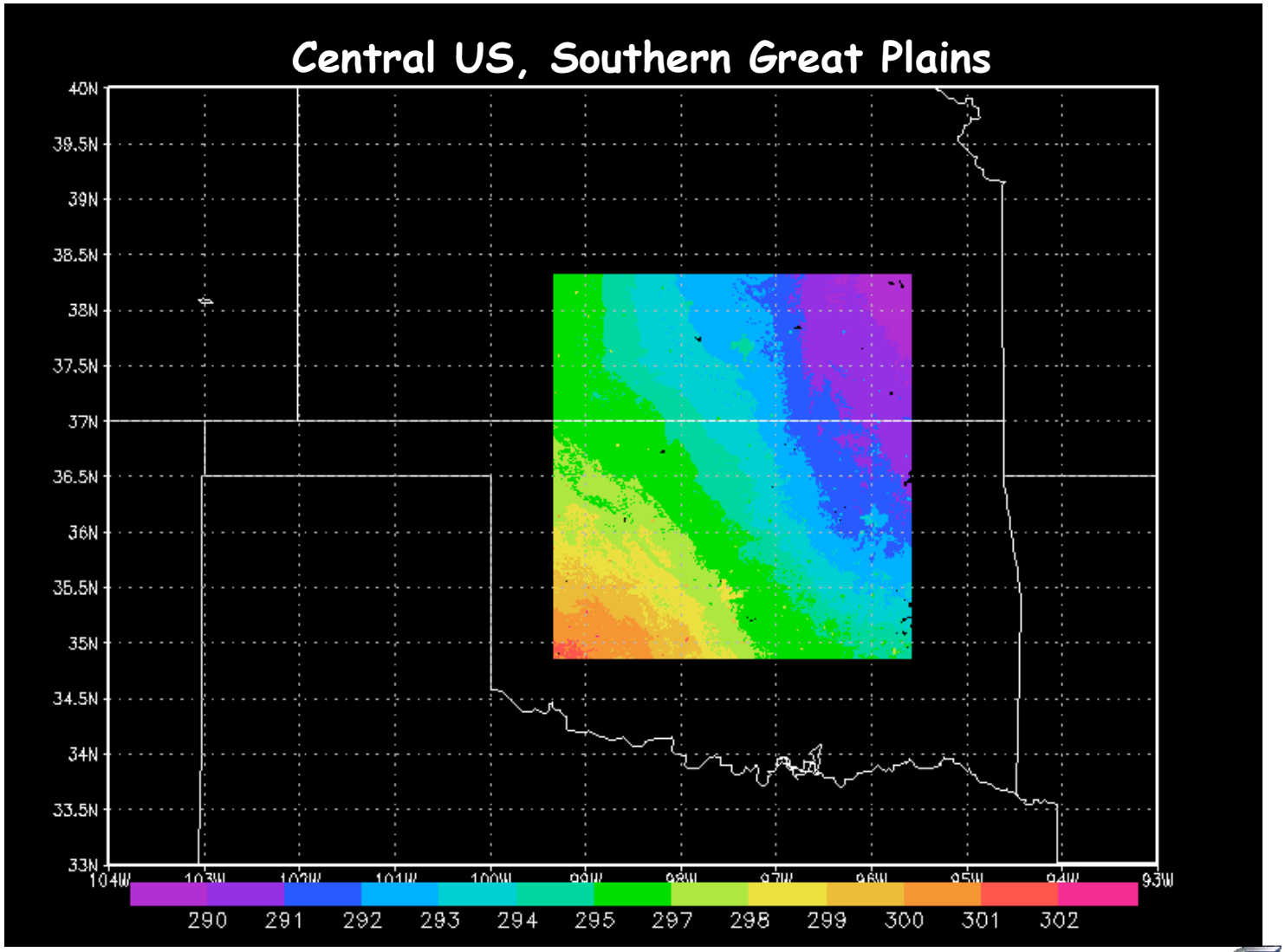


LIS-WRF

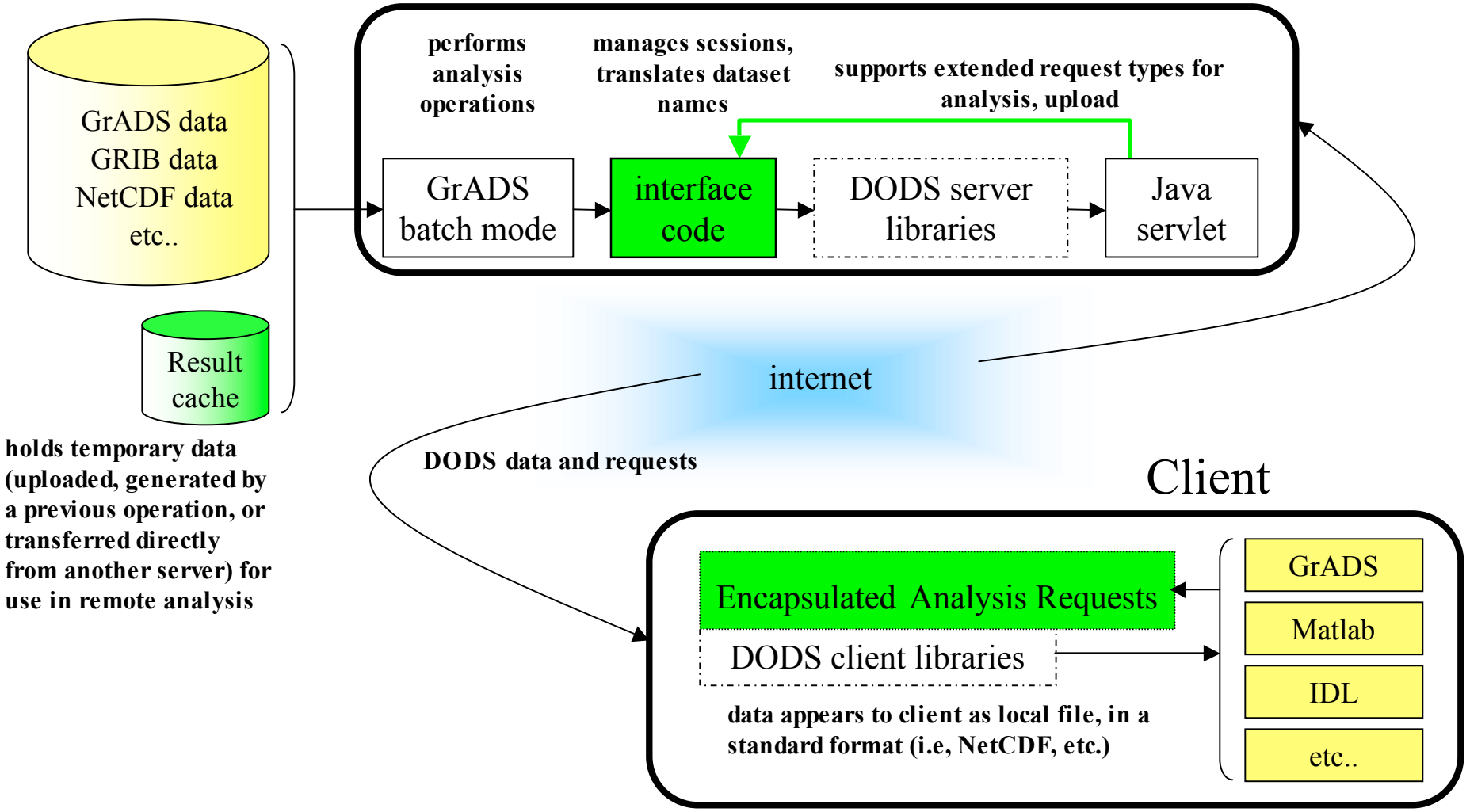


Evaluation Case Study:

International H_2O Project (IHOP), May-June 2002

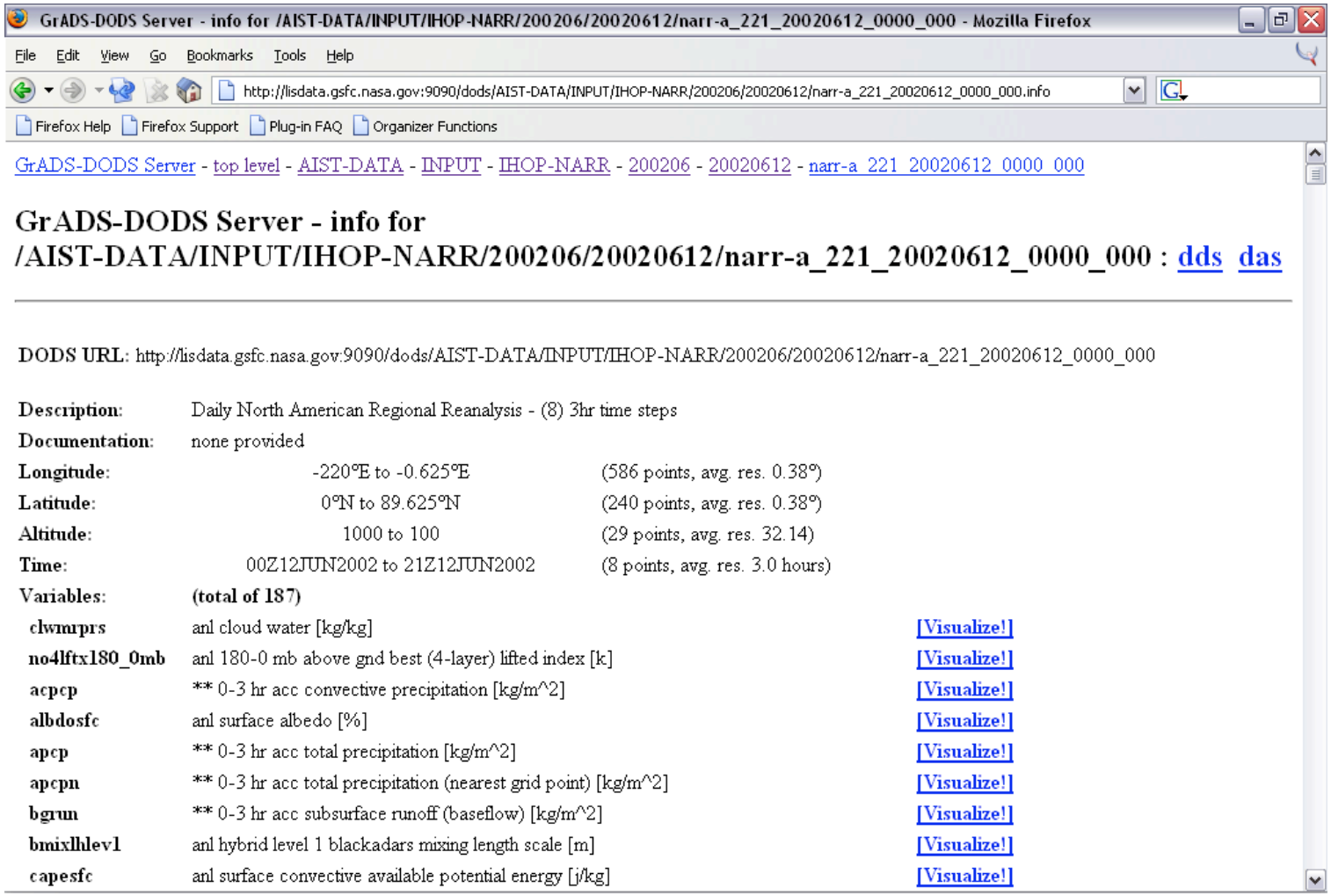


Evaluation Data Technology: GrADS-DODS Server (GDS) aka OpenDAP

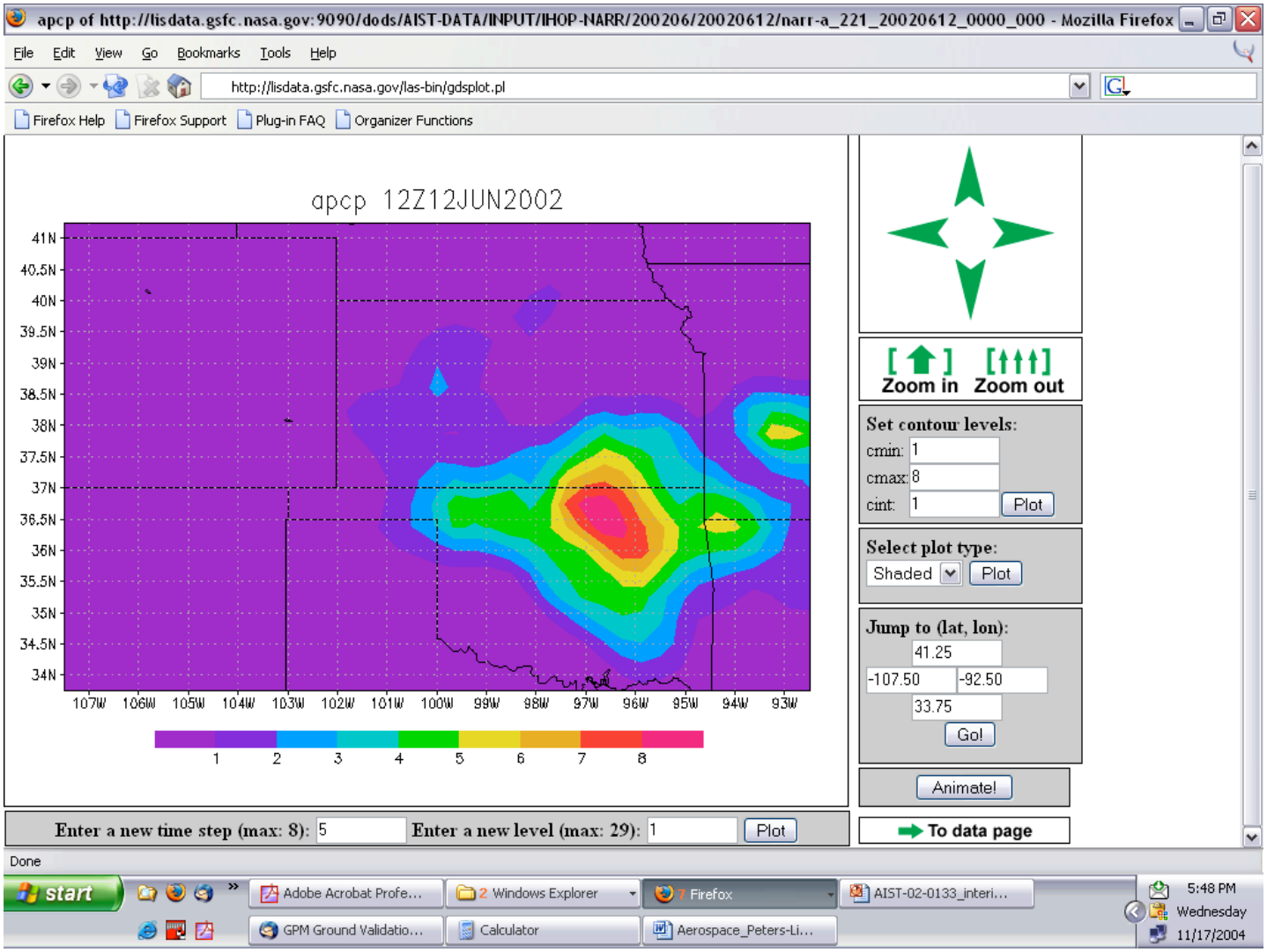


Joe Wielgosz: 5/25/00

GrADS-DODS Server (GDS) for IHOP

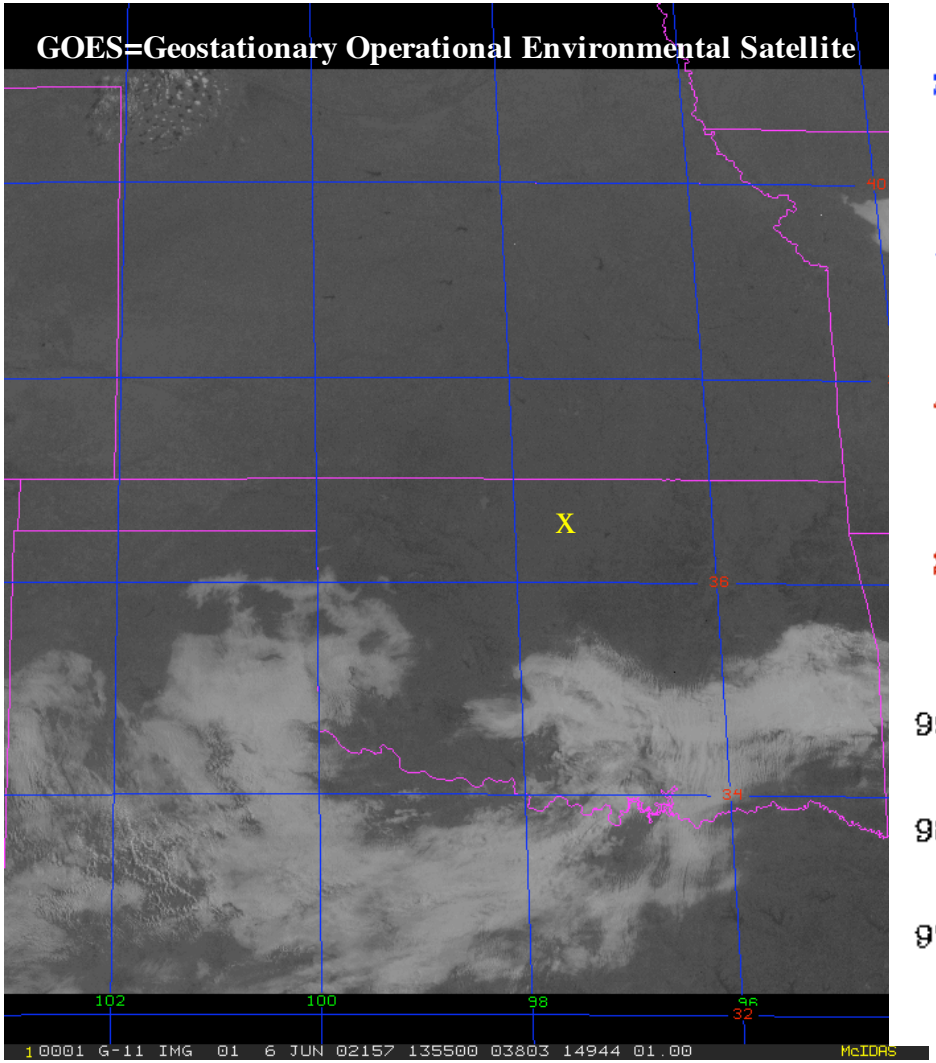


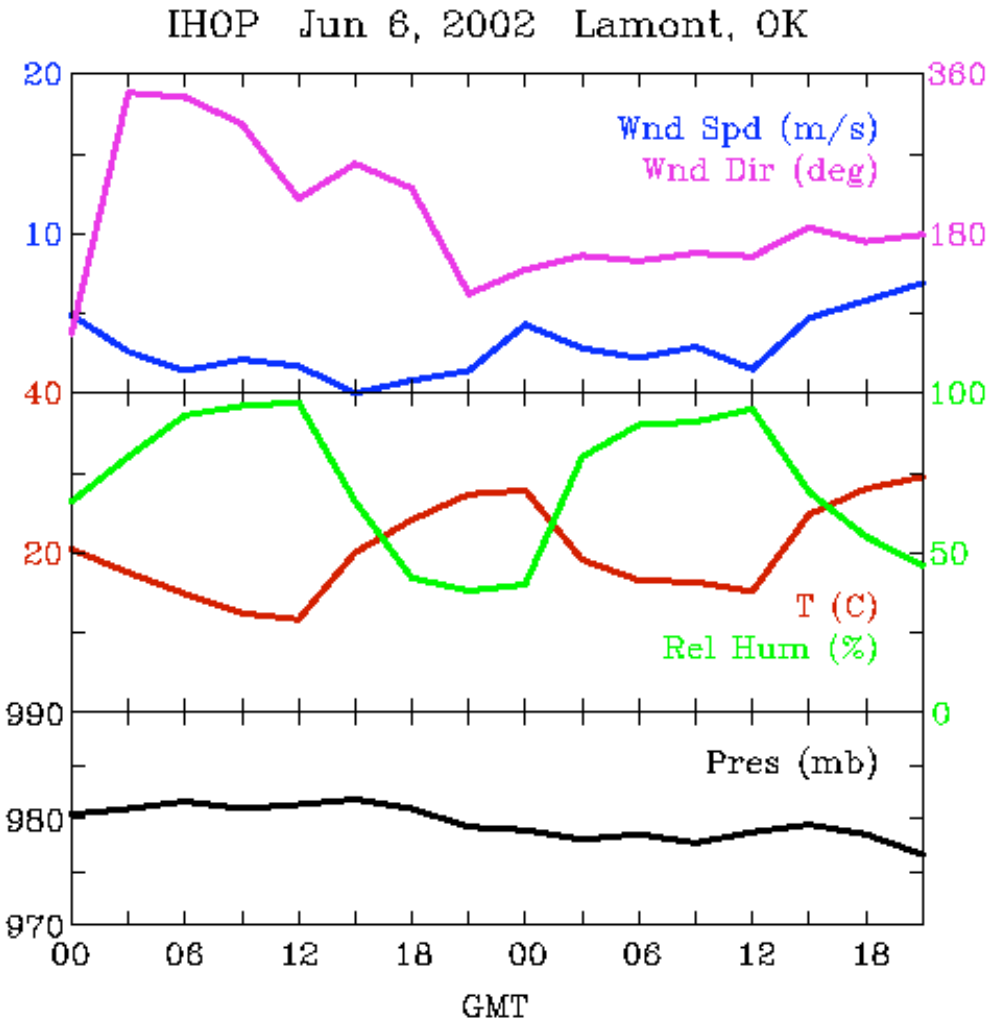
GrADS-DODS Server (GDS) for IHOP



IHOP "Golden Day" Synthetic Case
GOES Imagery & Sounding Data June 6, 2002

13:55 UTC





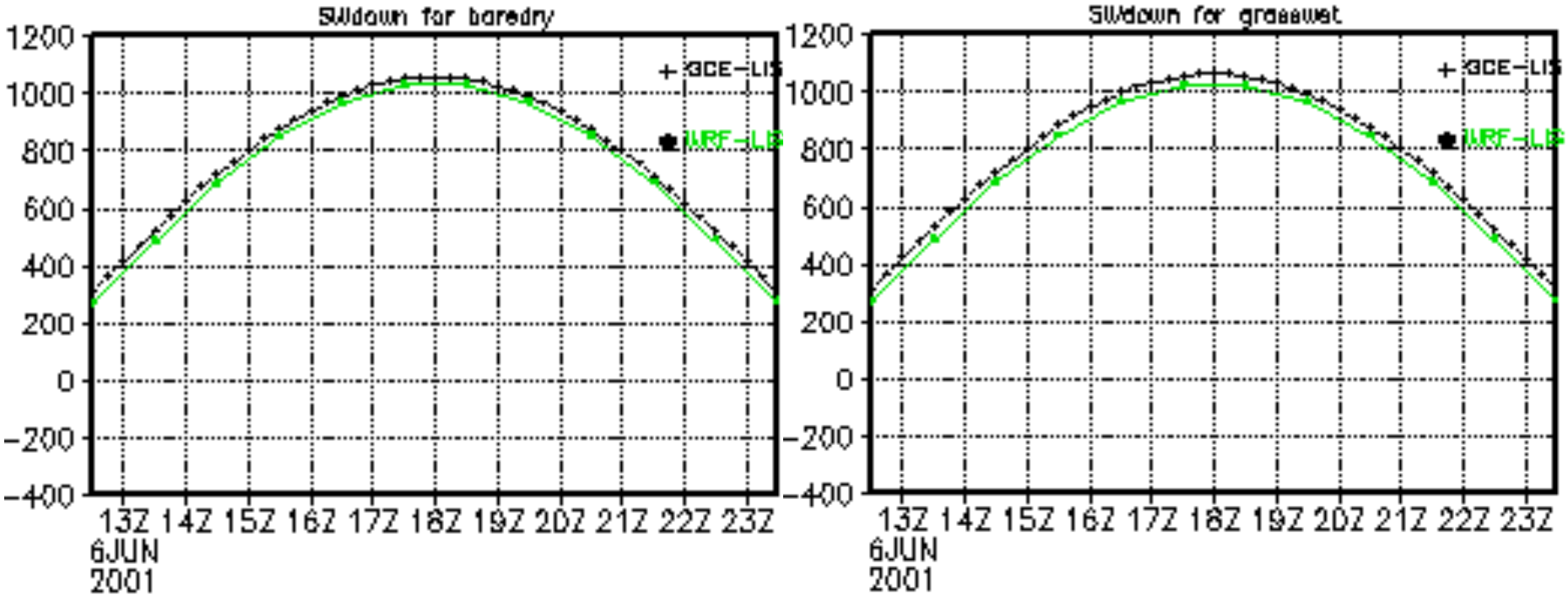
Synthetic Case Experimental Design

Soil Moisture Condition

Vegetation Condition	Dry	Wet	Half Wet/Half Dry
Bare Soil	Baredry	Barewet	Barewetdry
Vegetated (Grassland)	Grassdry	Grasswet	Grasswetdry

Synthetic Case Evaluation

Comparison of Input Radiation



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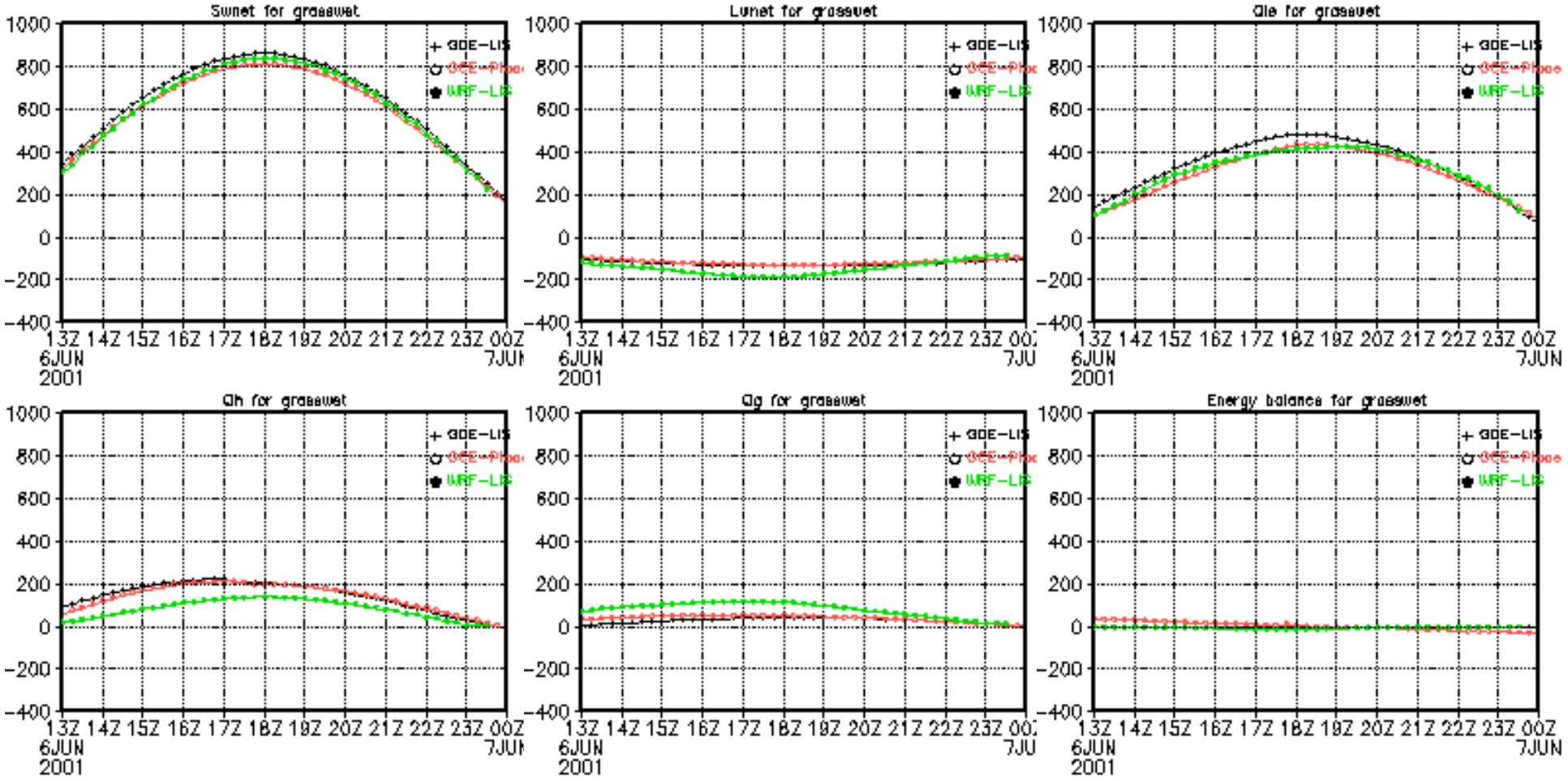
Synthetic Case Evaluation

Comparison of Energy Terms and Balance for Grasswet Case



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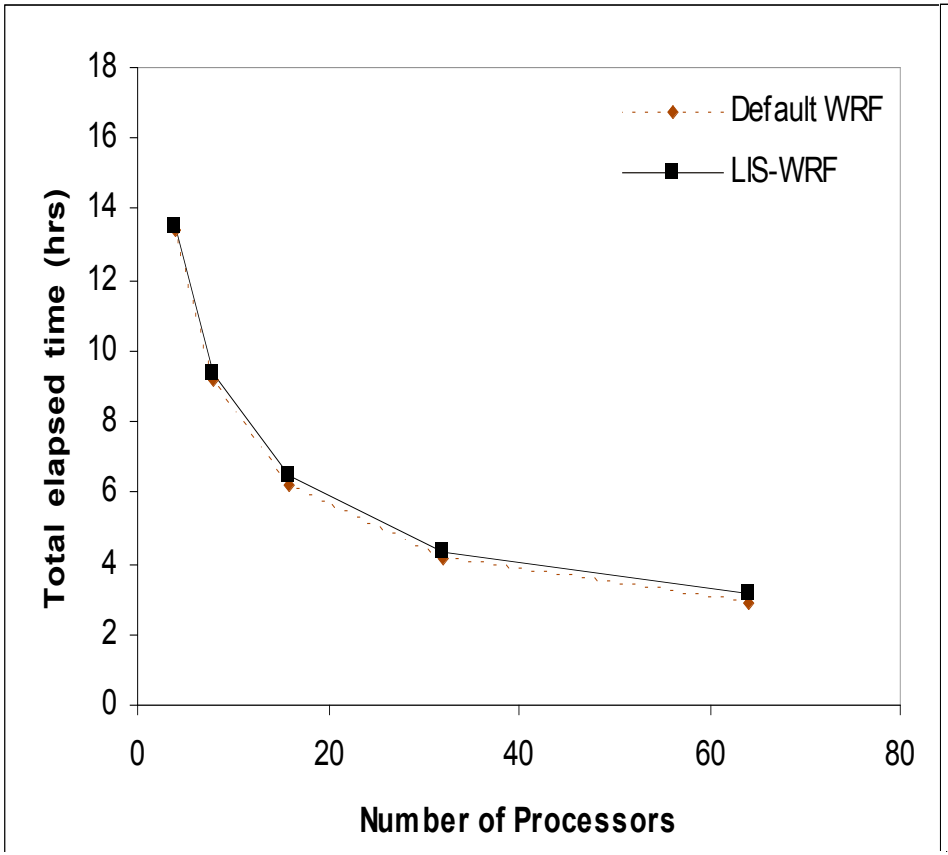
Synthetic Case Evaluation

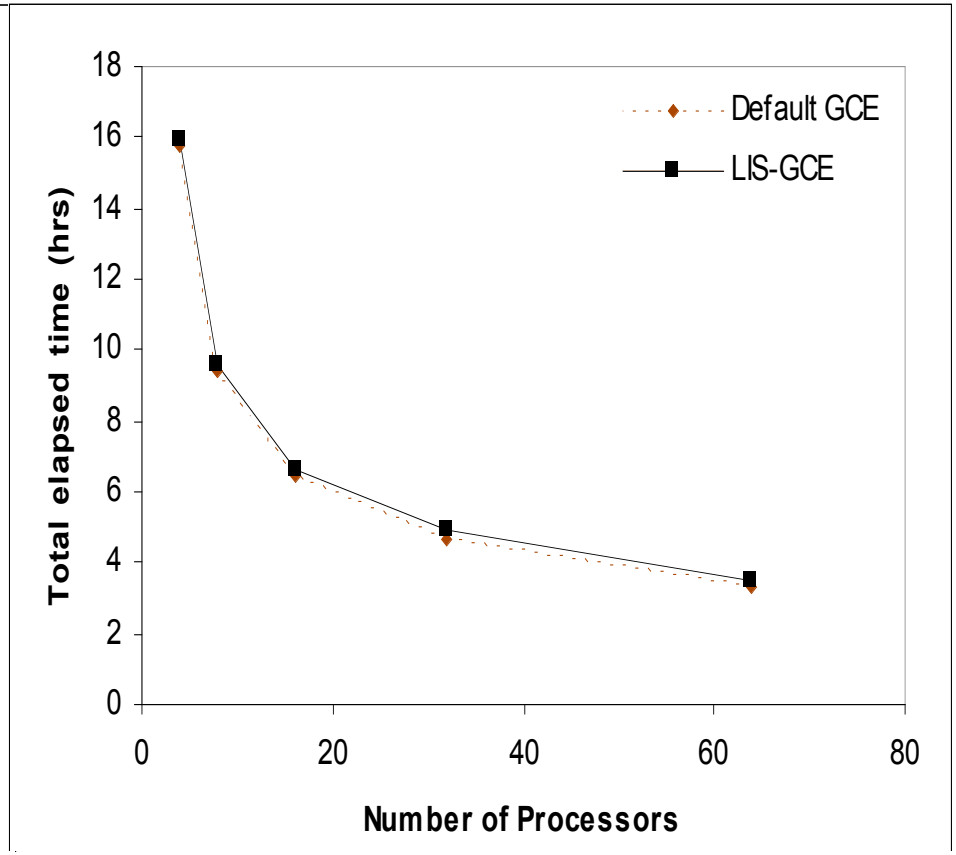
Factor Separation: Impact of Wet Soil and Grass Relative to Bare, Dry

Variable	Wet Soil	Grass	Interaction
GLW (Wm-2) Longwave Radiation	-4.7	3.1	1.4
SWDOWN (Wm-2) Shortwave Radiation	-2.0	4.3E-02	-1.6
HFX (Wm-2) Sensible Heat Flux	-155	39	-54
LH (Wm-2) Latent Heat Flux	176	-5.8E-03	116
Q2 (kg/kg) 2-m Air Humidity	3.82E-03	-1.80E-04	1.54E-03
T2 (K) 2-m Air Temperature	-5.49	0.26	-0.72
PBLH Planetary Boundary Layer Height (m)	-490	191	-149

Impact of ESMF on Coupled Performance

Weather Research and Forecasting Model (WRF) Goddard Cumulus Ensemble Model (GCE)

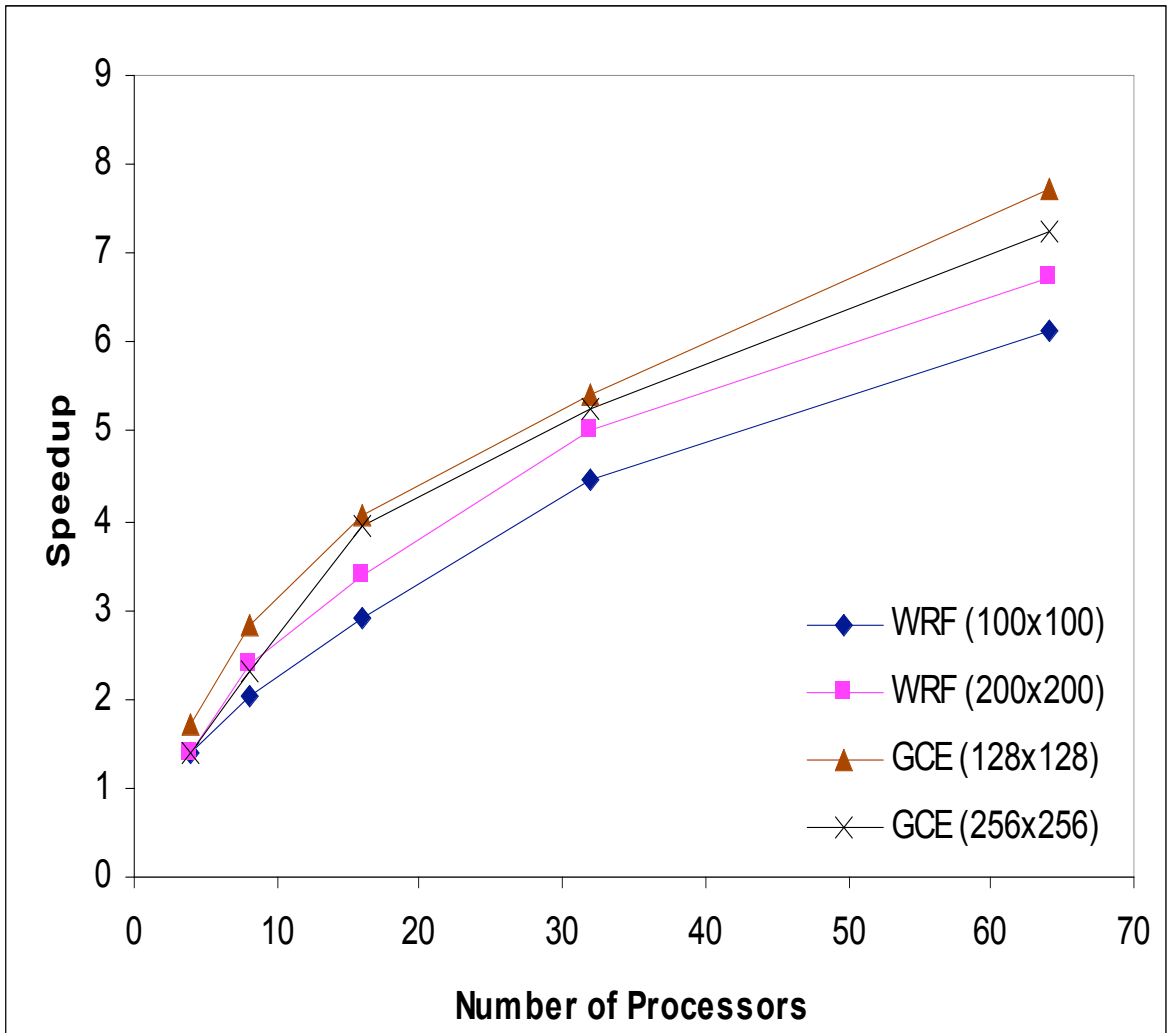




Key conclusion: ESMF-compliant coupling adds minimal computational overhead relative to native models

WRF/LIS and WRF/GCE

Performance scaling for the coupled systems



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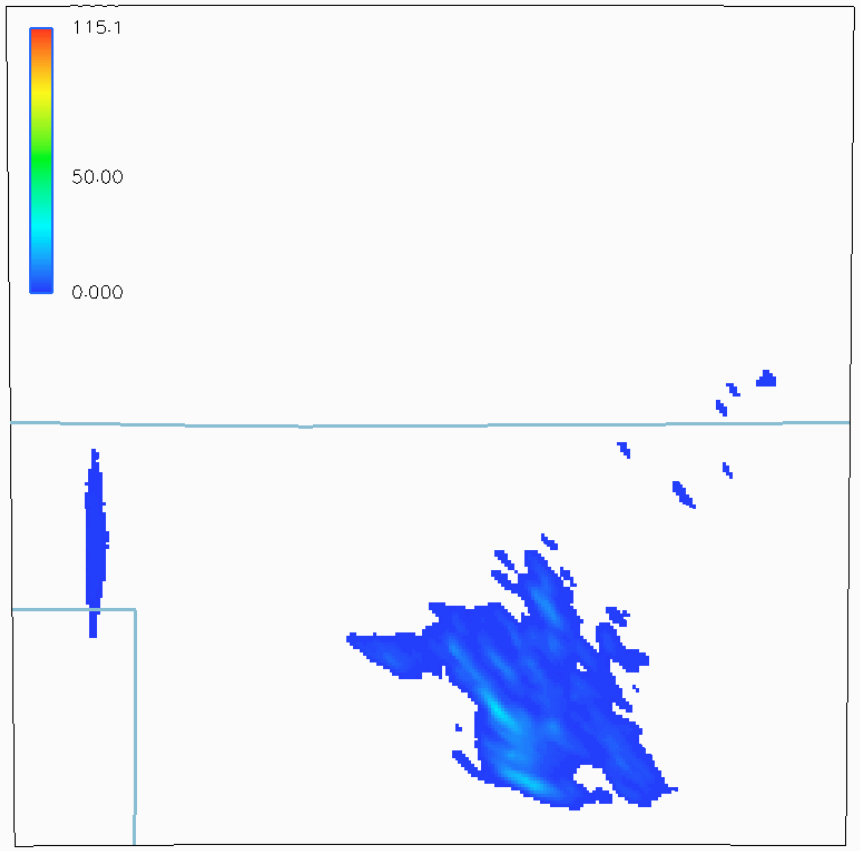
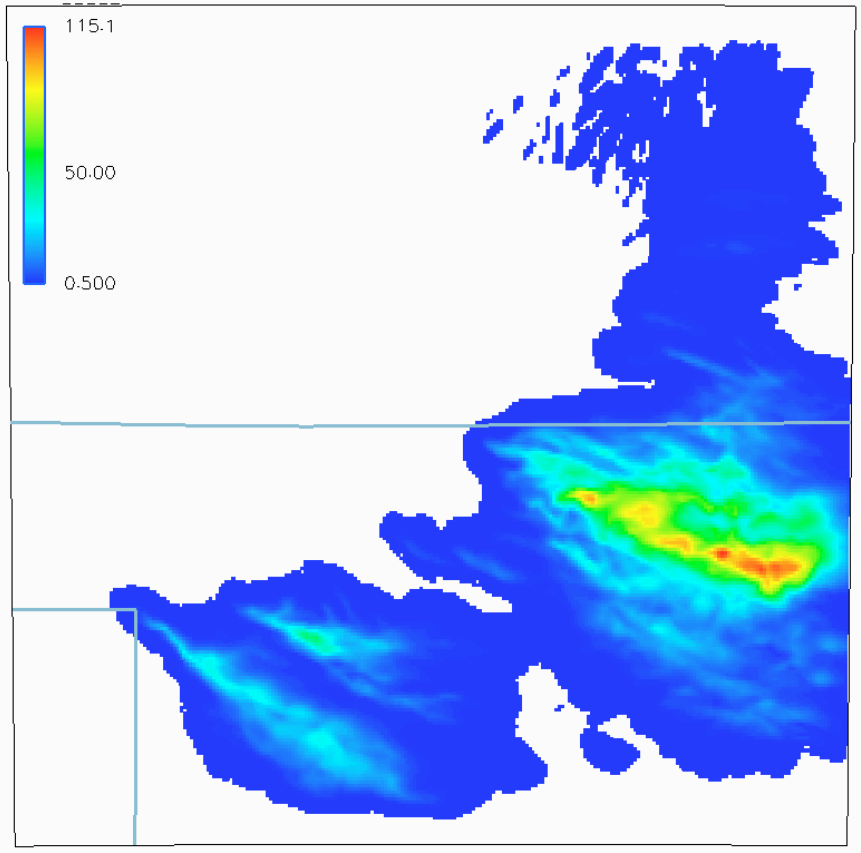
Scientific Evaluation: June 12 "Real" Case

Overview of LIS Spinup Impact on WRF+LIS Precipitation

24 hour accumulated precipitation with default soil initialization



24 hour accumulated precipitation with LIS 7.5 year spinup soil initialization



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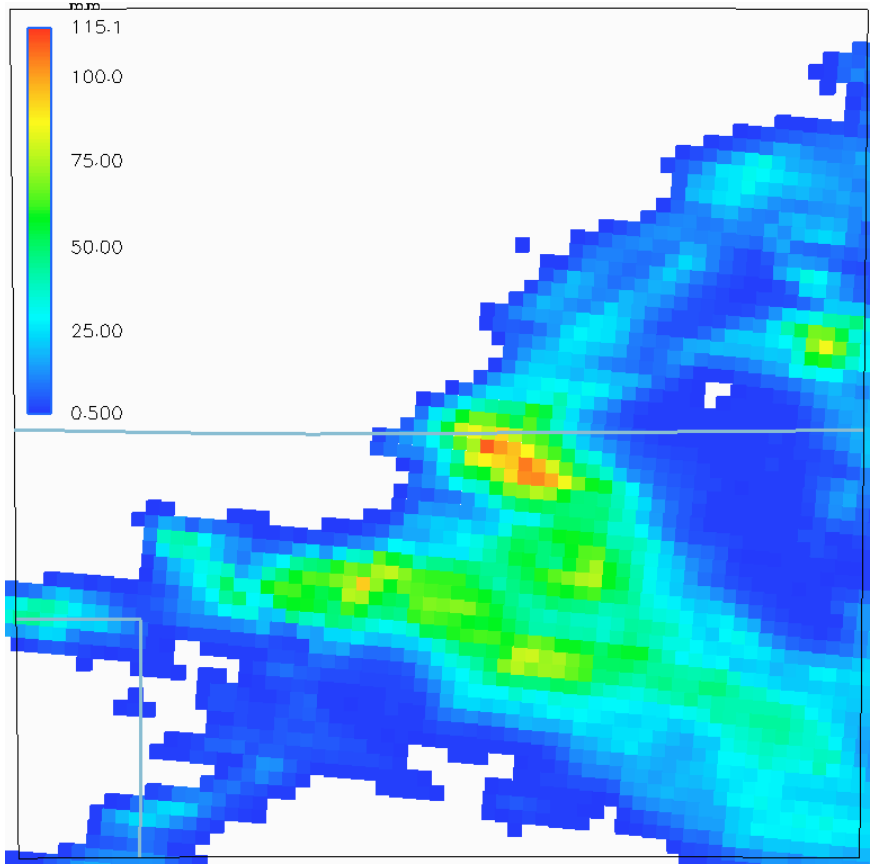
Scientific Evaluation: June 12 Case

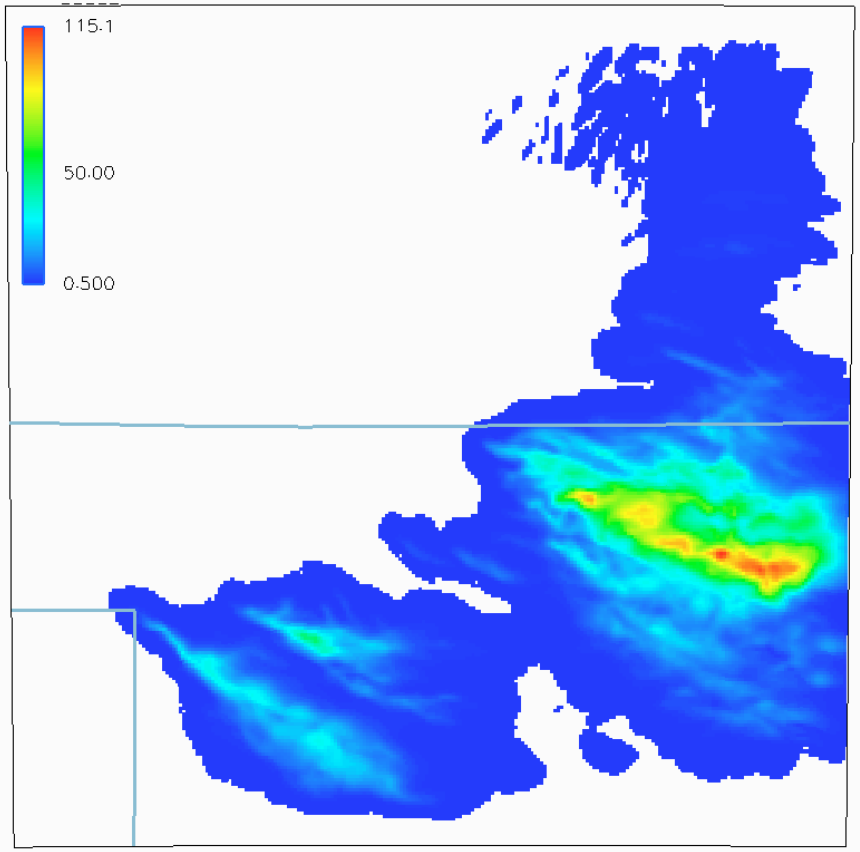
Radar Derived Precipitation vs. Modeled Precipitation (mm)

6GMT June13th, 2002

Observed Radar Derived Surface Precipitation (Source: NOAA/NCEP)



Modeled WRF+LIS Precipitation using LIS initial surface conditions



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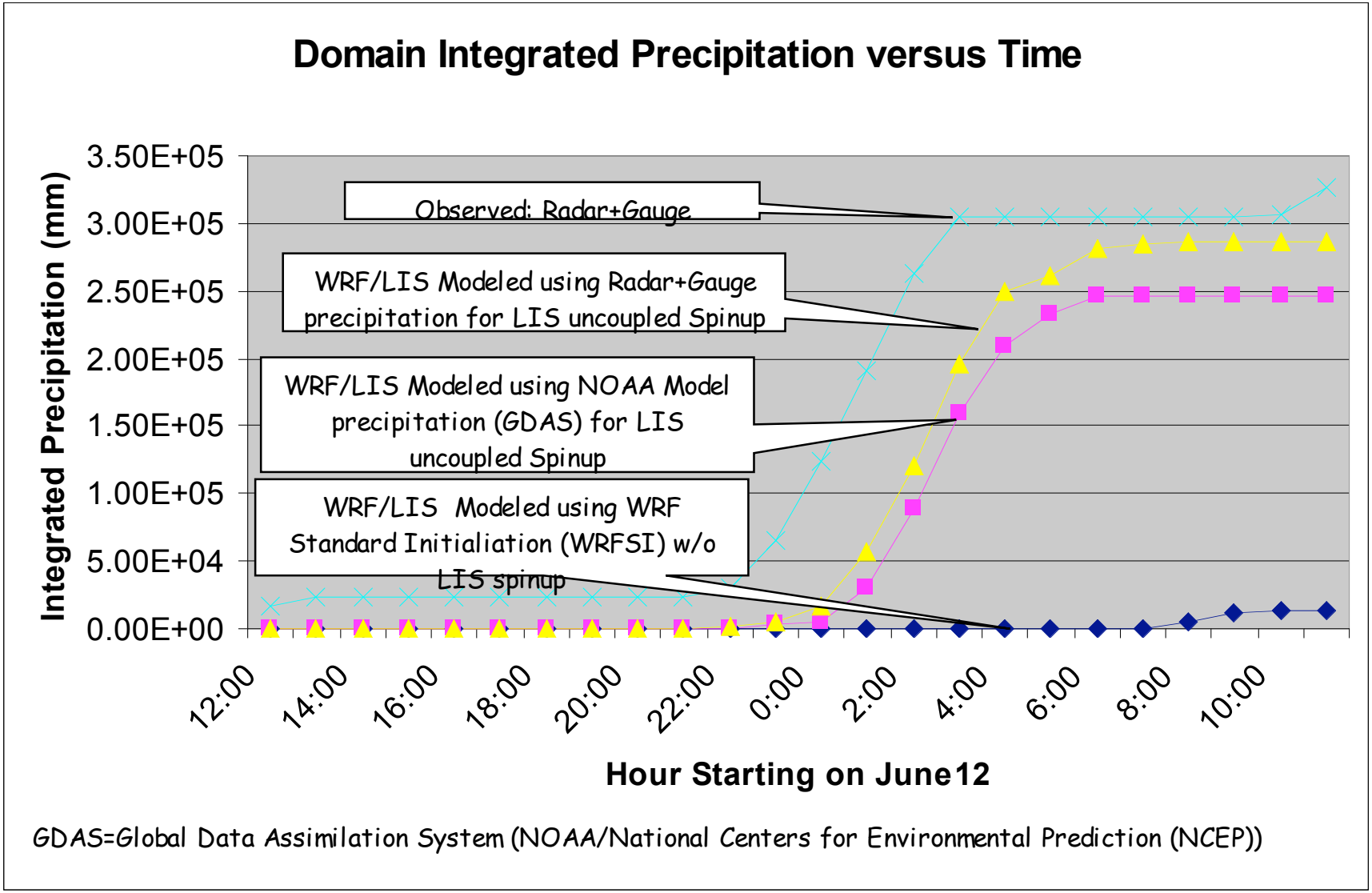
Scientific Evaluation: June 12 Case



GDAS=Global Data Assimilation System (NOAA/National Centers for Environmental Prediction (NCEP))

Project Highlights and Future Plans

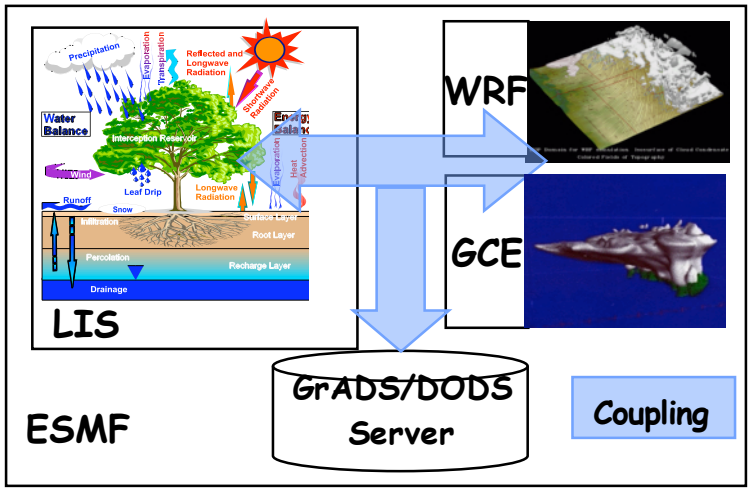
1. TRL Advancement
   - TRL3 technologies advanced to TRL4 (Goal: TRL6)
   - LIS-WRF is TRL5, working on LIS-GCE
2. Recognition
   - LIS selected as GSFC's 2005 Software of the Year Award nominee. NASA-wide competition June 22-23, 2005.
3. Technology Transfer to NOAA and DoD
   - LIS is currently being benchmarked for potential operational use at NOAA's National Centers for Environmental Prediction as well as the Air Force Weather Agency.
4. Benchmarking on Columbia
   - We have been allocated 150,000 hours on Columbia for benchmarking and additional scaling studies for the

Coupling High-Resolution Earth System Models Using Advanced Computational Technologies

Christa Peters-Lidard, GSFC

Objectives

- Apply advanced computational technologies to the problem of coupling high-resolution Earth system models
- Combine the emerging technologies of the Earth System Modeling Framework (ESMF), the Land Information System (LIS) and the Grid Analysis and Display System (GrADS)/Distributed Oceanographic Data System (DODS) and couple them to the Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model to enable high-resolution modeling



Accomplishments

- Delivered design document for coupling LIS to GCE and WRF with ESMF.
- Populated LIS GrADS/DODS Server (GDS) with data for the 2002 International H2O Project (IHOP) experiment.
- Completed fully ESMF-compliant coupling of LIS and WRF and LIS and GCE
- Advanced the TRL 3 technologies in LIS and ESMF to TRL4.
- Completed IHOP synthetic and real cases with WRF, and synthetic cases with GCE
- Demonstrated improvement of precipitation prediction due to LIS/WRF coupling

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TRL_{in} = 3; TRL_{out} = 4